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Office of Civil Defense  
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EXPERIMENTAL PROTOTYPE PACKAGE VENTILATION  
KIT, FIRST STRUCTURAL AND  
HUMAN FACTORS TEST

by

B. A. Libovicz  
H. F. Behls

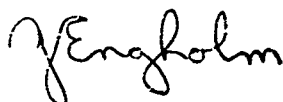
OCD Work Unit 1423A

GARD Report 1278-4.1

May 1965

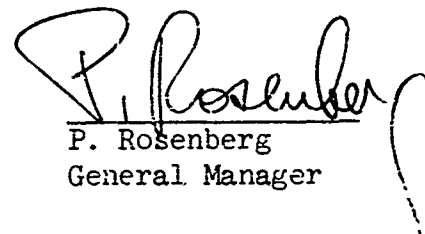
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This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

## FOREWORD

The structural and human factors analysis test of a survival shelter ventilating fan reported herein was conducted by the General American Research Division (GARD) of the General American Transportation Corporation (GATX), Niles, Illinois, during the period 29 March 1965 through 12 April 1965. The Package Ventilation Kit tested was an experimental prototype unit developed, designed, and fabricated under Contract OCD-PS-64-22 with Mr. R. G. Hahl of the Office of Civil Defense serving as project monitor. A second test will be performed on a preproduction prototype unit fabricated by the Fuller Company, Compton, California. This unit was developed under Stanford Research Institute Subcontract B-70925(4949A-28)-US with Mr. C. A. Grubb serving as project monitor.

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### ABSTRACT

A structural test and human limit evaluation of the shelter Package Ventilation Kit (PVK) showed that the ventilator can be readily operated for periods of at least three hours with 7-1/2 minutes rest each half-hour. The PVK can be operated at pedal speeds from 45 to 63 RPM, and the preferred speed was 55 RPM. The optimum power input was found to be 0.10 horsepower per operator, and the maximum tested was 0.15. Most tests were performed at comfortable conditions, 68 to 72 F effective temperature (ET). The maximum ET imposed was 83 F. Further tests are required to establish work/rest cycles when operating the PVK at elevated ET's.

This experimental prototype unit operated adequately for 331 hours, and then marginally for another six hours due to sprocket wear. As a result, the PVK specifications were revised to require hardened sprockets. One chain spring clip failed during the test; therefore, endless riveted chain has been specified. No chain wear was indicated. The saddle post rapid adjustment clamp caused jamming of the post. Since the seats are not adjusted frequently, this feature has been deleted and the standard bicycle saddle clamp is now specified. A clutch has been included in the crank assembly, but was not used during the test. Since no need for this device was expressed by either operators or observers, and since the clutch is expensive, the clutch has been deleted. Other observations have affected the design of the saddle, handle bar, and connecting joint. These design changes have been incorporated into the drawings and specifications. Prior to fabricating preproduction prototype Package Ventilation Kits, GARD recommends that another structural test be performed on the PVK. See GARD Report 1278-4.2, "Preproduction Prototype Package Ventilation Kit, Second Structural and Human Factors Test", performed by GARD and AIR under OCD Work Unit 1423A, SRI Subcontract No. B-70925(4949A-28)-US.

## TABLE OF CONTENTS

<u>SECTION</u>	<u>Page</u>
FOREWORD.....	ii
ABSTRACT.....	iii
LIST OF FIGURES.....	vii
LIST OF TABLES.....	viii
1 INTRODUCTION AND SUMMARY.....	1
2 STRUCTURAL ANALYSIS.....	5
2.1 Sprockets.....	5
2.2 Chain.....	9
2.3 Saddle Post.....	9
2.4 Saddle.....	9
2.5 Handle Bar.....	9
2.6 Clutch.....	11
2.7 Connecting Joint.....	11
3 RECOMMENDATION.....	12
SUPPLEMENT First Human Factors Test Report by the American Institutes For Research.....	13
Introduction.....	14
Description of the Apparatus.....	14
Approach.....	14
Method.....	17
Laboratory.....	17
Subject Recruitment.....	17
Subjects.....	19
Operational Routine.....	20

GENERAL AMERICAN RESEARCH DIVISION

TABLE OF CONTENTS (Cont.)

<u>SECTION</u>	<u>Page</u>
Observation Technique.....	22
Results and Discussion.....	23
Structural and Mechanical Considerations.....	23
Chain and Sprockets.....	23
Motor.....	24
Saddle Post.....	24
Connecting Joint.....	25
Noise.....	25
Machine Design Recommendations.....	25
Seats.....	25
Handle Bars.....	28
Clutch.....	29
Recommendations Regarding Operator Limitations.....	29
Fatigue and Body Soreness.....	29
Determination of Optimal Operating Conditions.....	30
Symptoms of Operator Stress.....	35
Other Operating Dangers.....	35
Unusual Operating Situations.....	36
Hand Operation.....	38
Team Make-Up.....	38
In-Shelter Operator Combination.....	39
Recommendations for Further Research Regarding Operating Factors.....	41

TABLE OF CONTENTS (Cont.)

<u>SECTION</u>	<u>Page</u>
Appendix A: Forms Used in the Recruitment and Processing of Subjects.....	42
Appendix B: Summary of Pedal Speed, Input Load, and Effective Temperature Tests.....	49
Appendix C: Electrical Recording of Heart Rate.....	51

LIST OF FIGURES

<u>FIGURE NO.</u>		<u>Page</u>
1	View of Test Set-Up	2
2	Schematic of PVK	6
3	Fan Assembly	7
4	Results of Sprocket Wear	8
5	Distorted Seat Post	10
6	Shelter Ventilating Unit -- Side View	15
7	Test Environment -- Plan View	18
8	Schematic of Electrode Placement	54
9	Cardiotachography Method 1	55
10	Cardiotachography Method 11	57



LIST OF TABLES

<u>TABLE NO.</u>		<u>Page</u>
I	Subject Information	20
II	Over-All Number of Subject Complaints about Seat Discomfort	26
III	Over-All Number of Times Seat Height Adjusted	27
IV	Number of Times Handle Bars Adjusted	28
V	Subject-Volunteered Indications of Fatigue, by Shift, In Subjects Who Worked Eight Shifts or More	29
VI	Subject-Volunteered Indications of Body Soreness, by Shift, In Subjects Who Worked Eight Shifts or More	30
VII	Duration of Tests Under Each Condition of Pedal Speed and Power Input	32
VIII	Mean Pulse Increase as a Function of Work Load and Speed	33
IX	Operators Relieved by Symptoms and Sex	35
X	Summary of Double-Shift Operation	37
XI	Efficiency of Operator Group Composition in Terms of Per Cent of Segments Reported Operating Below Required Speed	39
XII	Summary of Tests	50

## SECTION 1

### INTRODUCTION AND SUMMARY

A structural and human factors test of the Civil Defense fallout shelter Package Ventilation Kit (PVK) was conducted by the General American Research Division (GARD) of the General American Transportation Corporation (GATX) and the American Institutes for Research (A.I.R) at the latter's Research Shelter Management Laboratory located at Pittsburgh, Pennsylvania. The pedal or motor operated ventilating fan was developed, designed, and fabricated by GARD under Contract OCD-PS-64-22, OCD Work Unit 1423A, for the Office of Civil Defense.

The test was run continuously for two weeks (see Figure 1) and no difficulty was experienced operating the unit manually. The unit can be driven easily at pedal speeds from 45-63 rpm, and input powers not exceeding 0.15 horsepower per operator when operated at comfortable temperatures. Two operators pedaled continuously for three hours at 55 rpm and a power input of 0.15 horsepower per man (Test No. 14, see Supplement, page 50). One of these operators worked the previous three hour shift at a work/rest cycle of 22.5/7.5 minutes. The operators were composed largely of local college students. Further tests are required to establish work/rest cycles necessary when operating the unit at elevated temperatures.

The structural failures were worn sprockets, distorted saddle posts, and a broken chain connecting link. All failures have been corrected -- the sprockets by hardening the teeth, the saddle post by deleting the slot in the post and using a standard bicycle saddle post clamp, and the chain by specifying endless riveted. Other observations that have affected the design were the saddle, handle bar, clutch, and connecting joint. The cost

of the Kit has been decreased by specifying a cheaper saddle which has the same comfort, and deleting the clutch in the crank assembly. Increasing the size of the handle bar, and decreasing the clearance in the connecting joint have made the operation of the unit more comfortable.



Figure 1 VIEW OF TEST SET-UP

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A·I·R provided the necessary human factors support, and their human factors and human limits evaluation are included in the Supplement. Observation technique included recording wet-bulb, dry-bulb, and effective temperature, tracking intrashift manning changes, taking pulse and blood pressure of operators, and noting mechanical or human difficulty encountered during operation.

Evaluation and recommendations offered were:

1. Durability - The ability of the apparatus to withstand two weeks of continuous operation by untrained personnel.

The apparatus operated adequately for 331 hours, and marginally for another six hours due to sprocket wear. Operation beyond 337 hours would have been difficult to achieve due to slippage in the drive chain caused by worn sprockets.

Total downtime encountered during the test amounted to about one hour, caused chiefly by difficulty with a drive chain.

2. Human Factors and Safety - The appropriateness of the design for human operability at minimum cost.

Suggested modifications based on obtained human factors data include:

- a. Elimination of the clutch at each pedal crank.
- b. Deletion of handle bars attached to a saddle.
- c. Elimination of handle bar adjustment.
- d. Modification of saddle anchoring and adjustment for both safety and economy.

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3. Optimal Operating Conditions and Human Limits Power input characteristics for safe and efficient operation by occupants of a fallout shelter.

Based on limited data, tentative limits and optima are offered as follows:

<u>Factor</u>	<u>Minimum</u>	<u>Optimum</u>	<u>Maximum</u>
Pedal Speed	45 RPM	55 RPM	63 RPM*
Horsepower Per Person	--	0.10	0.15
Effective Temperature, F	--	68° - 72°	83°
Operating Team Make-Up	3 Females	4 Males	--

It is recommended that persons with poor general health or circulatory disorders be excluded from the operating staff, and that any operator whose pulse while working is more than 40 beats higher than pulse after resting be relieved.

4. Danger to Bystanders - The only likely danger to bystanders arises from the leg weakness experienced by many operators upon dismounting, which causes them to stagger. For this reason, small children, elderly, and injured persons should be kept from the immediate vicinity.

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\*Although the apparatus was operated at 67 RPM, it is believed, on the basis of data collected, that this speed entails undesirable and unnecessary strain on operators.

## SECTION 2

### STRUCTURAL ANALYSIS

The Package Ventilation Kit consisted of three modules identified as A, B, and C (see Figure 2). The duration of the test was 337 hours at pedal speeds ranging from 45 to 67 RPM, and generally at an input power of 0.1 horsepower per operator. Refer to the Supplement, Appendix B, Table XII, page 50, for a summary of the tests.

The structural failures were (1) excessive wear of both 17-tooth sprockets in the transmission, (2) breakage of the module-to-module chain A-B connecting link, and (3) distortion of the module C saddle post. These failures are identified on Figure 2. No other failures occurred. Other factors which were observed and that have affected the design and specifications were (a) the saddle, (b) the handle bar and locking device, (c) the clutch, and (d) the module-to-module and module-to-fan connecting joints.

#### 2.1 Sprockets

Severe wear of the two 17-tooth sprockets in the Fan Assembly (Figure 3) occurred (see Supplement, page 23). The 75-tooth sprockets showed little, if any, wear. Corrective action taken was to specify hardening of these sprockets as follows (see Drawings 1423A-1103-2 and 1423A-1105-2 of Section 2.2, Specification MIL-V-40645):

"Heat Treatment: Carburize approx. 0.015 Deep, Induction Harden and Temper to Rockwell C40-45".

The wear is believed to be due to (1) chordal action of the chain on these sprockets, and (2) severe shock loads caused by the intermittent power strokes by the operators. Figure 4 compares the worn sprockets with a new sprocket.

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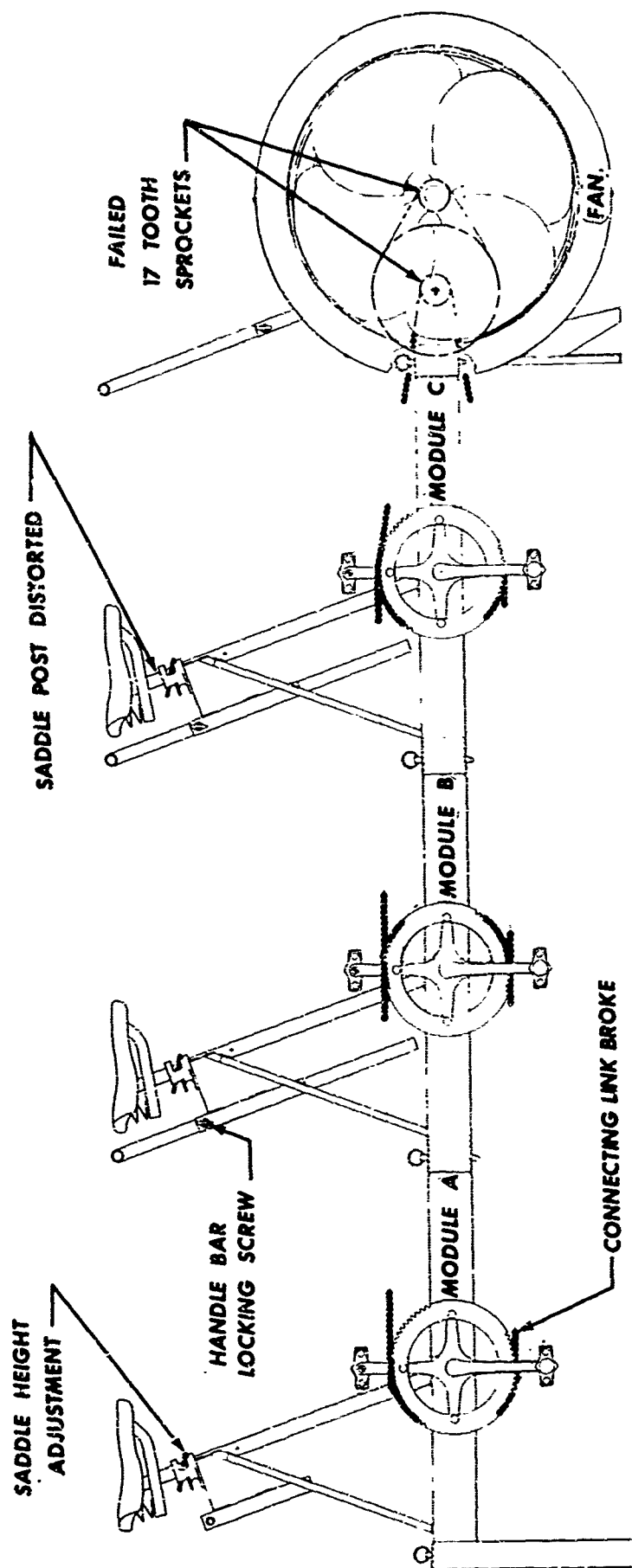


Figure 2 SCHEMATIC OF FVK

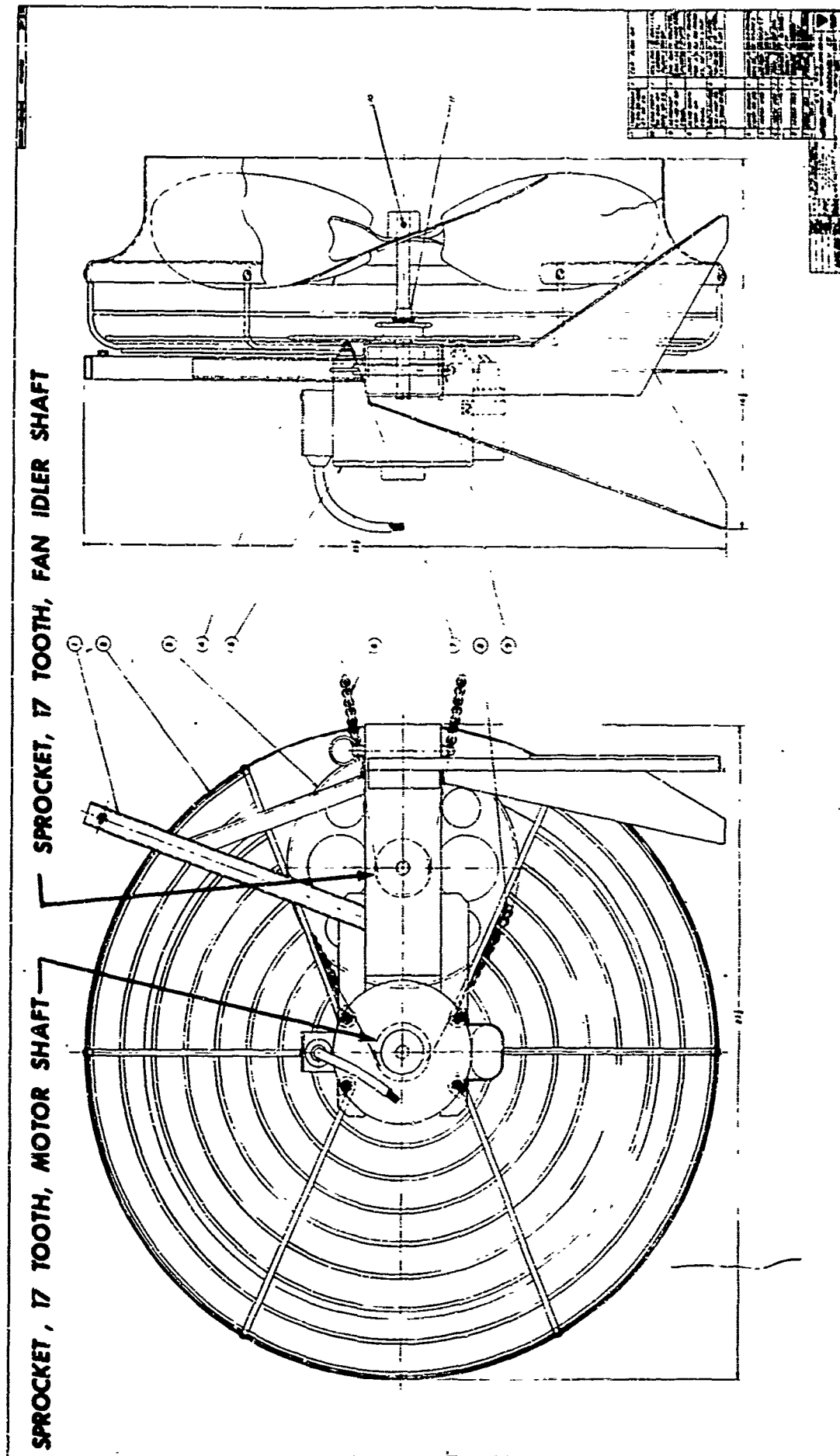
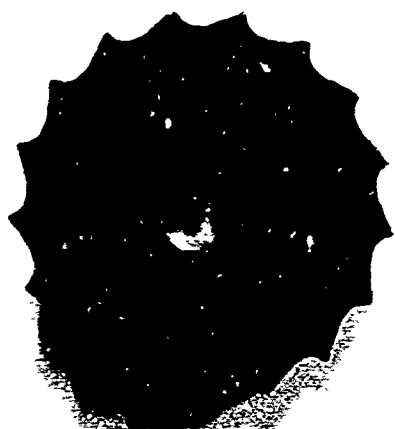


Figure 3 FAN ASSEMBLY

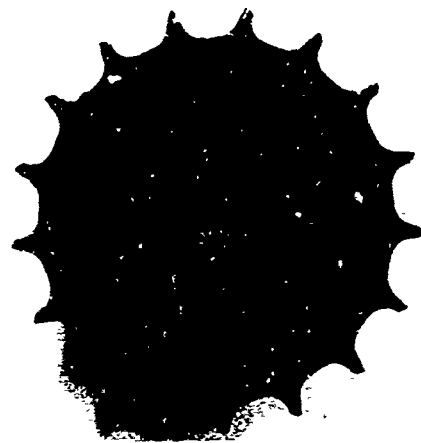
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## **SPROCKETS AFTER FIRST TEST**

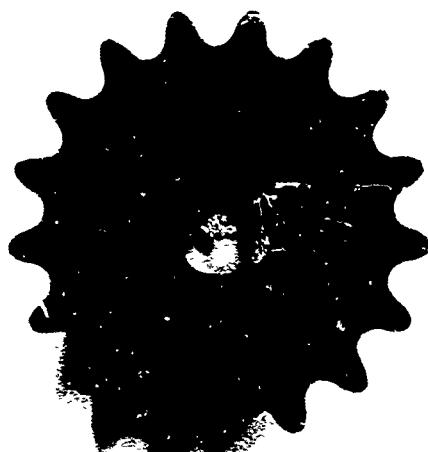


**IDLER SHAFT**



**MOTOR SHAFT**

## **NEW SPROCKET**



**Figure 4 RESULTS OF SPROCKET WEAR**

## 2.2 Chain

All chains showed little wear if any; however, the spring clip of the connecting link in the module A-B chain broke after 94 hours of operation (see Supplement, page 23). No other chain failures occurred. Due to this failure the connecting link has been deleted and all chains on the production unit are to be endless riveted (see Section 3.4 of Specification MIL-V-40645).

## 2.3 Saddle Post

The slotted saddle post used with the pinch-type, rapid adjustment clamp at module C distorted extensively (see Figure 5). Since this type of clamp is not necessary, as reported by A·I·R (see Supplement, page 27), the design has been revised to use a standard bicycle saddle clamp. With this modification a cost saving of \$0.83 per module is realized.

## 2.4 Saddle

Since no real difference in comfort existed between Mesinger Model M-7E and CZ-27 (see Supplement, page 25) the latter saddle is specified in Specification MIL-V-40645 (see Dwg. 1423A-1200). This results in a savings of \$0.11 each.

## 2.5 Handle Bar

As reported by A·I·R (see Supplement, page 28) the fan frame handle bar was too short and the thumbscrew used for locking the handle bar position could not be tightened sufficiently by hand to keep the bar from working loose. The handle bar size has been increased, and the thumbscrew changed from 1/4-20 UNC to 3/8-24 UNF. The longer head and the finer pitch thread of the 3/8-inch diameter screw provides the greater mechanical advantage needed to lock the handle bar.

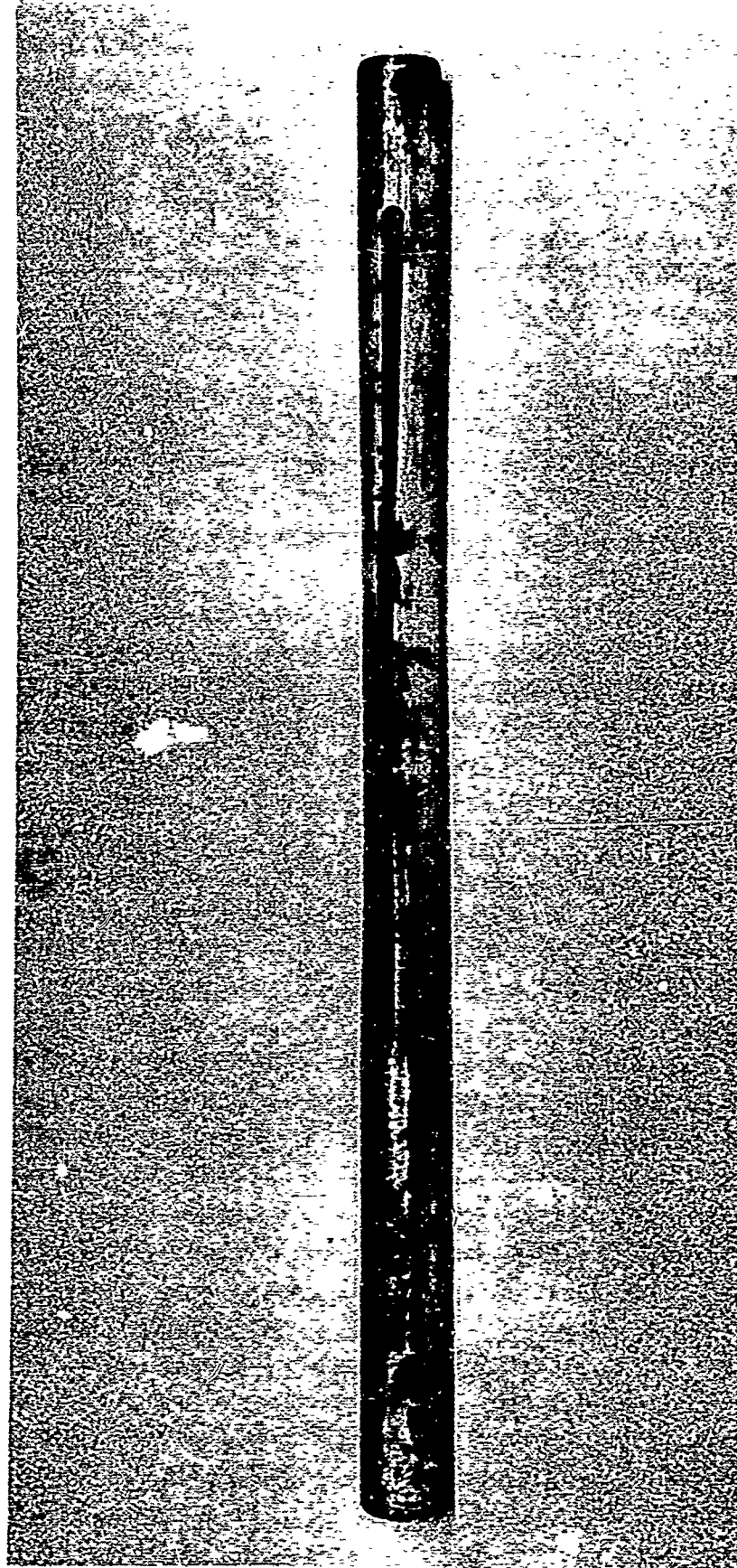


Figure 5 DISTORTED SEAT POST

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## 2.6 Clutch

The clutch in the crank assembly was not used during the test (see Supplement, page 29). No problems were encountered with the crank phase positions fixed relative to each other. The clutch has not been included in the design of the production unit. Since fixed cranks are a potential hazard, operation of the unit should be supervised. Deletion of the clutch results in a savings of from \$4 to \$7 per module.

## 2.7 Connecting Joint

As reported by A·I·R (see Supplement, page 23) the module-to-module chain A-B jumped off the sprockets on at least four occasions. No other chains jumped off the sprockets during the test. Also reported was some side-to-side wobble in the joint between module C and the fan housing (see Supplement, page 25). The jumping of the chain was due to misalignment of the module sprockets, and the wobbling was due to excessive clearance in the joint between the mating parts. This has been corrected by decreasing the respective tolerances.

### SECTION 3

#### RECOMMENDATION

The prototype PVK unit tested revealed structural failures and other design changes which would reduce the cost of the unit without reducing its performance, comfort, and stability. These design changes have been incorporated into the drawings and specifications. Prior to fabricating pre-production prototype Package Ventilation Kits, GARD recommends that another structural test be performed on the PVK. See GARD Report 1278-3.2, "Pre-production Prototype Package Ventilation Kit, Second Structural and Human Factors Test" by GARD and A.I.R. under OCD Work Unit 1423A, SRI Subcontract No. B-70925(4949A-28)-US.

SUPPLEMENT

EVALUATION OF AN EXPERIMENTAL PROTOTYPE  
PACKAGE VENTILATION KIT:  
FIRST HUMAN FACTORS TEST

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General American Transportation Corporation

## INTRODUCTION

In the event of nuclear attack, a large measure of America's ability to survive will depend on our system of public fallout shelters. To be effective, however, these shelters must be equipped to assure safe living conditions in a variety of emergencies. One quite probable emergency occurrence would be power failure, and the problem then arises of how to maintain atmospheric purity in the absence of electrically operated ventilating systems. One approach to the problem is to use a pedal-powered emergency ventilating apparatus. The subject covered in this report is the human factors evaluation of one such machine, manufactured by the General American Research Division (GARD) of the General American Transportation Corporation, 7449 North Natchez Avenue, Niles, Illinois.

### Description of the Apparatus

The machine can be technically described as a portable, pedal-powered or motor-driven emergency shelter ventilating kit. The version tested consisted of one fan unit designed to be powered by an electric motor or a mechanical drive, and three interchangeable modules, each equipped with an adjustable seat and handle bar, and bicycle-type pedals, crank, and sprockets. The fan and modules are mounted in tandem and ASA No. 35 chain connects module-to-module and the forward-most module to the fan. A clutch is designed into the crank assembly to allow one of the operators to mount or dismount without stopping the unit. The system is stored unassembled and is designed to be quickly set up by persons having minimal technical knowledge. Written directions for assembly and deployment are to be included in the kit. Figure 6 shows the apparatus as it was initially set up. (Later in the evaluation module A and module B seats were transposed.)

### Approach

The evaluation of the Package Ventilation Kit (PVK) was carried out in cooperation with GARD engineers and involved the study of the

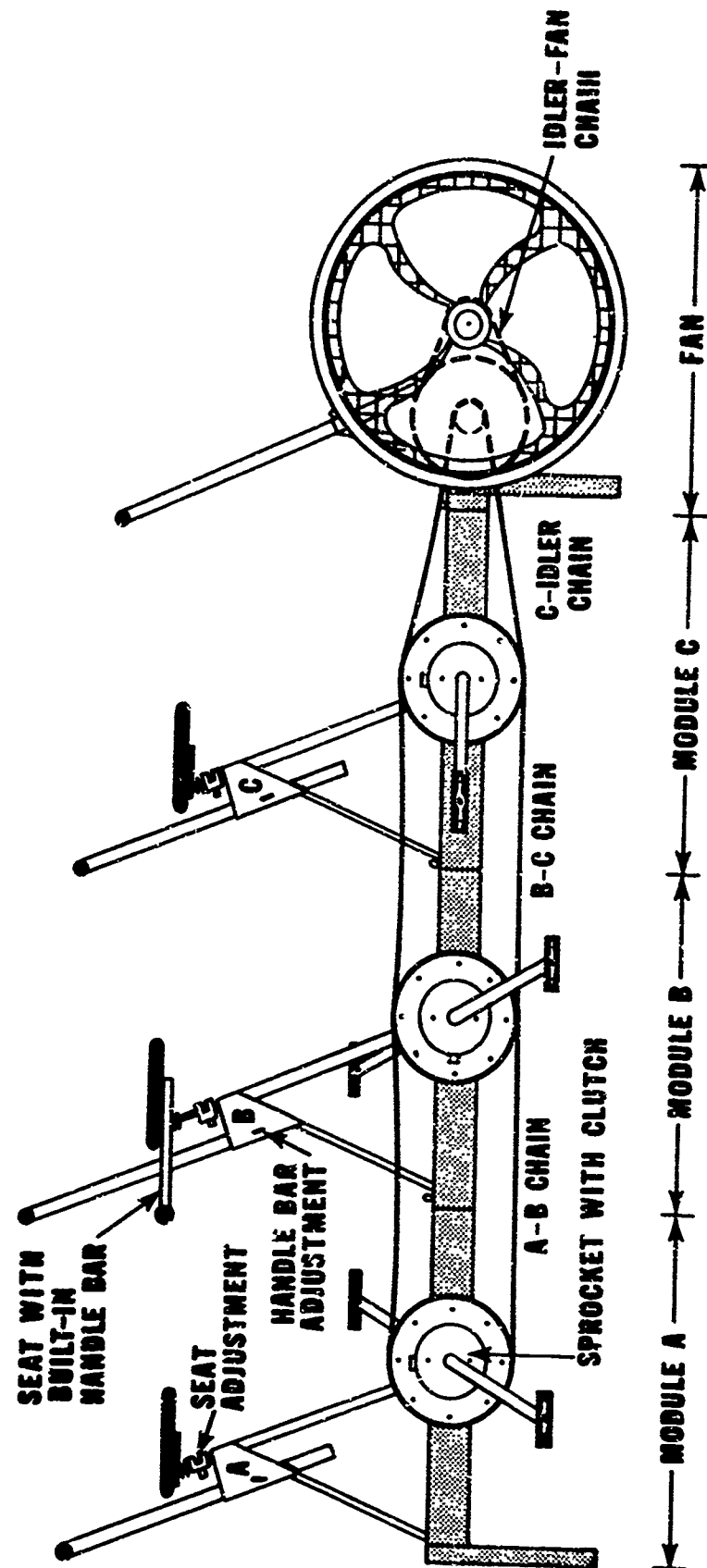


Figure 6 SHELTER VENTILATING UNIT -- SIDE VIEW



machine's structural and mechanical characteristics in addition to the evaluation of the machine in terms of human factors, and the estimation of human limits under which the system must operate. The staff of the American Institutes for Research gathered data relevant to all three areas and will present it below, and each aspect will be discussed as fully as the data warrant. A.I.R's areas of responsibility, however, lay with the human factors and human limits evaluation and it is here that greatest emphasis will be placed.

Pilot work for this human factors project consisted of imitating with a bicycle exerciser, the conditions under which a subject would work in order to determine, in a rough way, what would be required of the subject in terms of strength and endurance. Individuals of varying ages and physiques volunteered to pedal the exercycle and their participation provided the information necessary for the development of operational procedures and recruitment of subjects.

The actual evaluation consisted of operating the apparatus in a continuous, 337 hour run, beginning at 5:00 p.m., 29 March 1965 and concluding at 6:00 p.m., 12 April. This period, approximately 14 days, is considered to be the probable shelter confinement time following a nuclear attack.

In addition to A.I.R's program of evaluation, during the run, A.I.R cooperated with GARD engineers in a series of tests in which required pedal speed, input load, and ambient temperature were varied in an attempt to study as wide a range of possible operating conditions as the time available would permit.

## METHOD

### Laboratory

The evaluation was carried out in A.I.R's shelter research laboratory. The ventilating apparatus was installed in the simulated fallout shelter as shown in Figure 7. Approximately 25 feet of steel and plastic duct were extended in a straight line downstream of the fan and an air flow meter<sup>1</sup> was installed in the duct downstream of an air straightener. Input load was controlled by constricting the plastic duct at a point about 12 feet in front of the fan and fan speed was measured by means of an electric tachometer,<sup>2</sup> visible to both the subjects and the observer. Wet- and dry-bulb temperatures were taken with an aspirating psychrometer at the observer's table and these temperatures converted to effective temperature. Temperature and humidity were maintained by natural ventilation supplemented, when necessary, by the building's forced-air heating system.

### Subject Recruitment

Based on previous experience, it was decided that subjects would be most likely to make an effort to participate if they could be scheduled for more than one hour at a time. This factor, in conjunction with the endurance limits derived in a pilot run, imposed a safe maximum of three hours a day subject participation. Also, as the result of pilot work, the decision was made to operate with four-subject teams so that each subject might have a rest period, pedaling the apparatus 22-1/2 minutes of every half-hour and resting 7-1/2 minutes. It was on this basis that subjects were recruited.

Subjects for the evaluation were found mainly in the local colleges and universities. On-campus student employment services were contacted initially, then flyers describing the evaluation were posted on campus bulletin boards. Finally, personal contact was made with representatives

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<sup>1</sup>Taylor No. 3132 Anemometer

<sup>2</sup>Electro Products Laboratories Model 7101

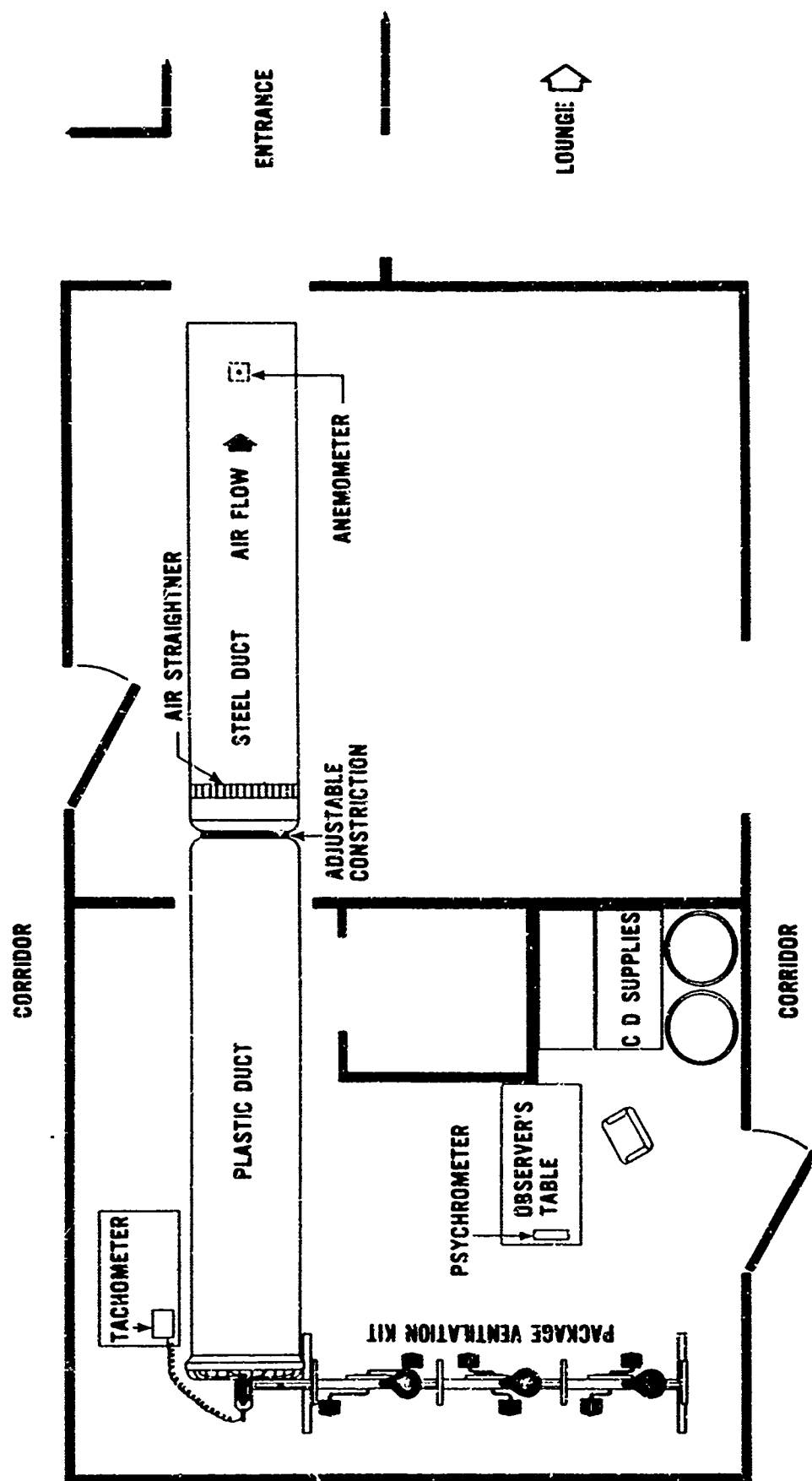


Figure 7 TEST ENVIRONMENT -- PLAN VIEW

Of several fraternities and flyers with application blanks were provided for use by their memberships. (See Appendix A for the forms used.)

In addition to the college response, a great many participants were found within A·I·R itself. They, with their friends and families, provided an excellent source of subjects for the early days of the run when the subject pool was smallest, and also provided on-call operators for emergency fill-ins.

A large subject response came as the result of television coverage which the project received during the first hours of the run.

Prospective subjects were asked to complete an application. If, on the basis of this information, it appeared that a potential health problem might exist, the applicant was asked to have a Medical Recommendation Form signed by his personal physician.

Before actual participation, each subject (except A·I·R employees) signed a Release Form, accepting full responsibility for his own health and safety during the evaluation, but at no time were subjects allowed to participate or to continue participation if any indication existed of a health or safety hazard. (Copies of the Release and Medical Recommendation Forms are included in Appendix A.)

### Subjects

Table I summarizes the important subject variables. Certain properties of the subject population are especially relevant to the present evaluation:

1. The great majority of the subjects were young, i. e., high school and college age. (Eighty-four per cent of the subjects were under twenty-five years of age.)
2. A high percentage (fifty-seven per cent) of the subjects pedaled on more than one occasion. No attempt was made to control the frequency or total amount of a given subject's participation.

TABLE I  
SUBJECT INFORMATION

Item	Range	Mode	Median	No. of subjects for which there was no info. on given item
<b>Age (years)</b>				
Male	13-35	18/20	20	0
Female	14-47	21	20	0
<b>Height</b>				
Male	4'8"-6'4"	5'11"	5'10"	4
Female	5'0"-5'11"	5'5"	5'4"	0
<b>Weight (pounds)</b>				
Male	70-215	165	156	2
Female	100-165	115	120	0
<b>Times Participated</b>				
Male	1-15	1	2	0
Female	1-11	1	1	0

Number of Subjects (N) = 150

Number of Male Subjects = 93      Number of Female Subjects = 57

#### Operational Routine

As noted earlier, each subject was to operate the apparatus for 22-1/2 minutes and rest 7-1/2 minutes, or viewed in another way, three segments on, one segment rest. The concept of a segment is important here: A segment is that period of time (usually 7-1/2 minutes) during which the same combination of team members operate the machine. Since every 7-1/2 minutes one operating member is relieved by the resting member, the composition of the group operating the apparatus changes, thus the need to differentiate into segments.

The evaluation exercise was divided, then, into three-hour shifts, usually performed by four-member teams, with three operators on the machine, each person operating three segments and resting one, as explained above. This schedule will hereafter be called a normal shift.

Subjects were requested to arrive 15 minutes early in order to complete Applications and Release Forms. New subjects were familiarized with the physical set-up and operating procedures and, in latter shifts of the experiment, base-line pulse rate, blood pressure, height and body weight measures were taken.

Each day's shifts began at twelve midnight and changed every three hours thereafter. To achieve a shift change, three members of the new shift crew, at command, would simply exchange places with the three operating members of the old shift. The fourth member of the fresh crew would rest the first segment and normally relieve "A" position rider. This subject would rest one segment and then relieve "B" rider, and so on. (See Figure 6, page 15, for location of positions.) Thus, in the normal three-hour shift, each rider would man each seat position twice.

During the first few days of the experiment, subjects were allowed to eat or drink what they pleased, but later, participants were limited to water and Civil Defense survival crackers. Salt tablets were available if desired. Articles of clothing and newspapers used as seat padding were permitted on the assumption that such would be found in a fallout shelter. Subjects were allowed to entertain themselves in any way that did not interfere with the evaluation. Subject pastimes included reading, conversation, singing, and verbal games.

During the last week of the exercise, subject pulse and blood pressure were monitored to insure that no one exceeded his physical limitations. Pulse rate, taken at the wrist by digital pressure, was recorded at the beginning and end of each subject's rest period, and when the observer was extremely busy, each subject took his own pulse. The observer took blood pressure by means of a standard sphygmomanometer at regular intervals from each subject as he operated the apparatus. Riders were removed from the machine for any of the following indications:

1. Working pulse rate in excess of 140 beats per minute.  
(Some staff members stayed on the apparatus beyond this point at their own discretion.)
2. Systolic blood pressure in excess of 160 mm Hg.
3. Diastolic blood pressure in excess of 90 mm Hg if there were not compensatory increase in pulse rate.

Near the end of each shift each subject signed a pay receipt and collected his subject honorarium, and when his shift was relieved, he was free to go. Normal subject remuneration was \$2.00 per hour. Two shifts, however, the three to six a.m. and the six to nine a.m., were paid at the rate of \$2.50 per hour to encourage participation at these inconvenient hours.

#### Observation Technique

The observation staff for the exercise consisted of 13 A-I-R employees, and three persons from outside the organization. Initially only one observer was necessary, but later, as observer duties became more numerous and complex, two-man observer teams were used.

Observers were expected to maintain awareness of the over-all situation rather than to concentrate on any single aspect of the exercise. Besides the systematically recorded information (wet- and dry-bulb temperature, pulse rate, blood pressure, subject information, and subject's seat position per segment), the following general types of data were gathered:

1. The condition of, and the changes in the condition of, the machine.
2. The behavior, verbal and non-verbal, of the subjects, including indications of fatigue and boredom.
3. The interactions between the operators and the apparatus, including machine adjustments necessary and difficulties encountered.
4. Observer and subject comments and recommendations.

## RESULTS AND DISCUSSION

### I. STRUCTURAL AND MECHANICAL CONSIDERATIONS

Five areas of comment concerning the machine itself were collected from the observer record. These include worn sprockets, loose chain, saddle looseness, module looseness, and noise.

#### Chain and Sprockets

Module-to-module chain A-B jumped off the sprockets on at least four occasions. No other chains jumped off the sprockets during the test. At 1450 on 2 April (fourth day of the study) the connecting link of module-to-module chain A-B broke, causing a downtime of twenty minutes.

One serious machine difficulty which arose late in the run was a worn small sprocket on the idler wheel between the fan and "C" module. The first indication of trouble was recorded at 1230, 11 April (thirteenth day of the study), when the C-idler chain began to jump teeth of the small sprocket. The situation gradually worsened to the point where, from twelve noon, 12 April (fourteenth day of the study), to the completion of the exercise, a brass pipe had to be held against the C-idler chain to increase the tension and eliminate the teeth jumping. Without this device, efficiency would have been much reduced, input load increased, and the noise level raised to a nearly intolerable intensity. The motor sprocket was worn considerably; however, the chain did not jump teeth at first.

Operator behaviors were a contributing factor to the sprocket and chain malfunctions. Two types of such behavior, "lunging" and "revving," were isolated as seeming especially wear-producing. Lunging was the irregular, pulse-like application of power as the operator delivered power strokes with one leg only. Revving was a burst of speed, usually initiated by one operator, to the RPM limit of the tachometer (2000). These acts,



probably caused by boredom, resulted in greater strain on the machine than was necessary to accomplish its purpose and, if eliminated, could probably increase the useful life of the machine.

The most significant result of the mechanical testing aspect of the study is that, six hours prior to completion of the 337 hours of operation, the functioning of the apparatus was so severely impaired that extraordinary measures were required to complete the test. At its completion, worn and deteriorating sprockets permitted the module-to-idler drive chain to slip so continuously, in spite of the improvised tensioning device described above, that operation beyond 337 hours would have been exhausting to operators and minimally productive.

#### Motor

While the test indicated that adequate ventilation could be maintained without the use of the electric motor, it is felt that this result is not sufficient support for the notion of eliminating the motor from the PVK. If electric power is available in a shelter, the operation of the PVK by the motor would eliminate the additional management problem of staffing and scheduling operator teams, and this fact will be worth the additional cost of the motor. Then, too, it would increase the availability of people for assignment to other shelter operating tasks. Finally, it may prove to be most advantageous in shelters composed largely of children and/or older people for whom sustained operation of the PVK would be difficult. Further analysis of this question is necessary before a final decision is reached.

#### Saddle Post

On several occasions subjects reported that the saddles tilted or twisted uncomfortably. All three positions malfunctioned in this manner. Excess clearance between the slotted saddle post and the anti-rotation spring pin permitted this twisting. During the last half of the test, the spring pin in Module C worked out unnoticed. Subsequently, the saddle post twisted and bent causing it to jam inside the mast. As a result of this, application of considerable force was required to obtain vertical adjustment of the saddle.

Front-to-back tilting resulted from insufficient tightening of the saddle clamp on the saddle post. This was especially the case in the integral handle bar saddle where the presence of the handle bar made it possible to apply a greater torque than on the other saddles.

#### Connecting Joint

Some side-to-side wobble was observed in the joint between Module C and the fan housing. This resulted from excess clearance between the mating parts as they were manufactured. This wobbling could be produced by either applying a sudden impact on the module-to-fan chain or applying a torque on the fan housing handle bar. This wobble did not affect the stability of the PVK.

#### Noise

Some mention should be made concerning the noise level of the machine while in normal operation. Few subjects appeared to notice machine noise even though the room was small. It should be noted, however, that conversation in a normal tone of voice was difficult in the vicinity of the machine, and sleeping, at least at first, would have presented serious problems. One subject considered the noise "irritating". Should increase in noise level occur, such as with a chain slip, conversation and sleep could be made almost impossible and irritation increased to the point where a serious morale problem would exist in the shelter.

### II. Machine Design Recommendations

Study of information evolved from the evaluation run indicates that the apparatus has three component parts which could be modified: seats, handle bars, and clutch.

#### Seats

The most serious problem encountered with the seats concerned the black seat with built-in handle bar used initially at "B" position. This

component remained on "B" position for 48 hours, during which time the following conclusions were reached:

1. The built-in handle bar, used by the "A" operator, was too low to provide comfortable support.
2. The "A" operator usually struck his knees on the bar, especially if "B" seat was adjusted to a low position.

At 1830 on 31 March (second day of the study), "A" and "B" seats were transposed, thus eliminating inconvenience and the possibility of injury to "A" operator.

This saddle-handle bar, then, is definitely disadvantageous. Although the seat itself is not objectionable, the handle bar is nearly useless and often an outright hazard.

Besides the black seat used initially at position "B," a white seat of similar design, used at "A," and a smaller "racing"-type seat used at "C" were also evaluated. The technique of observation lent itself most readily to measurement of seat discomfort rather than seat comfort since discomfort information was much more often volunteered by the subjects. These comments are tabulated in Table II.

TABLE II

OVER-ALL NUMBER OF SUBJECT COMPLAINTS ABOUT SEAT DISCOMFORT

Sex	White Seat <sup>1</sup>	Black Seat <sup>2</sup>	Racing Seat <sup>3</sup>	Total
Male	18	13	9	40
Female	<u>9</u>	<u>4</u>	<u>8</u>	<u>21</u>
Total	27	17	17	61

<sup>1</sup> Mesinger Model L-7E

<sup>2</sup> Mesinger Model M-7E

<sup>3</sup> Mesinger Model CZ-27

Table II indicates the subject's direct response to seat discomfort in the sense that it represents spontaneous (unsolicited) comment. Table III is included on the grounds that the number of times a seat is adjusted is an indirect measure of seat comfort.

TABLE III

OVER-ALL NUMBER OF TIMES SEAT HEIGHT ADJUSTED

Sex	White Seat	Black Seat	Racing Seat	Total
Male	11	7	12	30
<u>Female</u>	<u>7</u>	<u>8</u>	<u>2</u>	<u>17</u>
Total	18	15	14	47

Since the data represent unsystematic sampling procedure, no firm conclusions can be reached. Suggestive trends are, however, that males complained more than females, and that males tended to dislike the white seat. Combining the data from Tables II and III indicates that the black seat and the racing seat were less bothersome than the white seat. One thing can be said with certainty: No one seat was critically comfortable or uncomfortable. The majority of the observer staff who also pedaled felt that no real difference in comfort existed, but most of those who did express a preference indicated the black seat as most comfortable.

Additional data on seat adjustment showed that the number of times a subject adjusted his seat decreased with the number of shifts worked, a fact supported by the observed fact that after several days the experienced subjects, even though they knew how, simply ignored the adjustment. Since extremes in height will be encountered in a shelter situation, some adjustment of seat height should be provided. The pinch-type, rapid adjustment mechanism now on the apparatus is unnecessary.

### Handle Bars

The adjustable handle bars initially used at positions "B" and "C," later also at "A," were generally acceptable to the operators. Complaints recorded centered around three problems:

1. The handle bar at "C" often came loose, pulling completely out or telescoping into its support under the operator's weight.
2. The bar at "C" was too short for some operators even at full length.
3. The finger-tightened adjusting screws often did not have sufficient tension to keep the bar from working loose.

Table IV shows how infrequently handle-bar adjustments were noted

TABLE IV  
NUMBER OF TIMES HANDLE BARS ADJUSTED

Sex	Position "A"	Position "B"	Position "C"	Total
Male	3	0	4	7
Female	<u>0</u>	<u>1</u>	<u>3</u>	<u>4</u>
Total	3	1	7	11

As with the seats, the more often a subject operated the apparatus, the less often he adjusted the handle bars. It should cause no harm, then, to eliminate adjustment altogether, provided that the bars are long enough to be used comfortably by a tall operator (on the assumption that bars set too high, as the average and short operators would find them, would be more comfortable than bars set too low). It was recorded that many operators used the handle bar behind them as a back or leaning rest. Setting the bar as recommended above would also facilitate this practice.

### Clutch

The clutch in the crank assembly was not used during the test, and no need was voiced for such a device by either operators or observers. This fact, together with the increased cost of manufacture incurred by including it, argues effectively against its use. One caution should be included here: One purpose of the clutch is to prevent the pedal and crank from injuring the dorsal side of the operator's leg should it slip from the pedal. It is not certain to what extent the clutch actually does provide safety of operation for the rider or to what extent its disposal would present a hazard.

### III. RECOMMENDATIONS REGARDING OPERATOR LIMITATIONS

A major concern of the project was to obtain some idea of the limitations of the operators themselves. This section includes discussion of subject performance in terms of pedal speed, load, and effective temperature. Data are also related to subject fatigue and increased work tolerance to repeated shifts, and examination of unusual operating situations and team make-up is made in order to provide a preview of probable occurrences during actual operation in shelters.

### Fatigue and Body Soreness

Tables V and VI give indications of fatigue and body soreness complaints made by the 15 subjects who worked 8 or more shifts, recorded by shift.

TABLE V  
SUBJECT-VOLUNTEERED INDICATIONS OF FATIGUE, BY SHIFT,  
IN SUBJECTS WHO WORKED EIGHT SHIFTS OR MORE

Sex	1st Shift	2nd Shift	3rd Shift	4th Shift	5th Shift	6th Shift	7th Shift	8th Shift and Beyond
Male	2	5	0	0	1	2	1	0
Female	0	0	0	1	1	0	0	0
Total	2	5	0	1	2	2	1	0

TABLE VI  
SUBJECT-VOLUNTEERED INDICATIONS OF BODY SORENESS, BY SHIFT,  
IN SUBJECTS WHO WORKED EIGHT SHIFTS OR MORE

Sex	1st Shift	2nd Shift	3rd Shift	4th Shift	5th Shift	6th Shift	7th Shift	8th Shift and Beyond
Male	0	3	1	3	0	0	0	0
Female	<u>0</u>	<u>0</u>	<u>0</u>	<u>2</u>	<u>2</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	0	3	1	5	2	0	0	0

While the sample size is too small to provide unequivocal indications, certain patterns are interesting:

1. Indications of fatigue were volunteered more often by males than females.
2. Over both sexes, fatigue indications appear initially, disappear, then reappear with repeated shifts.
3. Over both sexes, body soreness seems to appear when fatigue indications first decrease.
4. Both fatigue and body soreness complaints appear to diminish with repeated participation.

The last fact is, perhaps, the most interesting from the point of view of the project. It seems to suggest that although the apparatus is initially uncomfortable for prolonged operation, eventually a point is reached where discomfort and fatigue begin to lessen. The fact that fatigue is recorded more often in males is discussed later, under Team Make-Up.

#### Determination of Optimal Operating Conditions

Any findings based on physiological measures are subject to two major limitations: First, measurements of pulse and blood pressure were taken by

non-medical personnel and are therefore of imperfect accuracy. Second, there were no controls over subject activities during intervals between their shifts, which allowed subjects to report for duty with artificially elevated or depressed pulses.

Pedal speed and work output per person were varied to find the optimum combination of these variables in terms of high work output and low fatigue for the operators. (See Table VII., Speed ranged from 45 RPM to 67 RPM, and work load from 0.043 horsepower 0.15 horsepower per person. Since the system was designed at 0.1 horsepower per person, this output was adopted as a base at which most pedal speeds were tested.

Blood pressures were taken chiefly as a prophylactic measure, and being rather subject to error, were not analyzed for this report. Pulse-rate measurements were instituted after the fifth day, and were continued until the conclusion of the study. As each shift of operators arrived, a "base pulse" was taken while they were at rest. Throughout the shift, a "working pulse" was taken as each operator's rest period began. A "resting pulse" was obtained at the conclusion of each rest period.

1. Pedal Speed: It appeared a priori that at a given work load, pulse rate would vary directly with pedal speed, since at very high RPM, most of the operator's energy is consumed in simply overcoming internal friction and inertia. This hypothesis was tested by subtracting "base pulse" from mean "working pulse" for each operator for each shift. This derived measured yields "pulse increase" for each operator for each shift. Inclusion of the "base pulse" tends to cancel differences between individuals, and using the "base pulse" measured at the shift in question tends to cancel differences (due to off-duty activities, etc.) within individuals. Table VIII on page 33 gives mean "pulse increase" under varying conditions of speed and work load, and also indicates the number of subjects from whom these data were obtained.



TABLE VII

DURATION OF TESTS UNDER EACH CONDITION OF PEDAL SPEED AND POWER INPUT

Pedal RPM	Horsepower Per Operator							Temperature
	0.043	0.09	0.10	0.12	0.123	0.137	0.15	
45			33 hrs				6 hrs	Comfort Range
48							9 hrs	Comfort Range
51.5	2 hrs		22 hrs					Comfort Range
55			52 hrs				19 hrs	Comfort Range
59			42 hrs	3 hrs	23 hrs	25 hrs	3 hrs	Comfort Range
59		24 hrs	25 hrs					77-83°F ET
60			24 hrs					Comfort Range
63			1 hr					Comfort Range
67			24 hrs					Comfort Range

TABLE VIII

## MEAN PULSE INCREASE AS A FUNCTION OF WORK LOAD AND SPEED

HP/Person	45 RPM	55 RPM	59 RPM
0.10	19.4 (N=18)	18.4 (N=13)	29.5 (N=29)
0.15	No Data	29.0 (N=7)	No Data

It is apparent then, at least in the range tested, that pulse rate is least elevated by work done at pedal speeds below 59 RPM. At the lowest pedal speed tested, 45 RPM (which was maintained for 33 hours at 0.10 horsepower per person), two operators were removed due to dangerous blood pressure readings, another suffered knee cramps, and the duct was mysteriously torn, probably by a rider in an attempt to ease the work. Nine operators out of 12 commenting said that this condition was more difficult than 59 pedal RPM at the same work output per person.

At the highest speed tested, 67 RPM, which was held for 24 hours at 0.10 horsepower per person, one operator was unable to finish his shift, pedal speed frequently dipped below that specified and there was one case each of headache, abdominal pain, and knee cramps. Four operators of twelve commenting said that this condition was more difficult than 60 pedal RPM at 0.10 horsepower per person. Since this test occurred early in the series, the effects of prior practice probably would cause the repeating operators to feel that this condition was easier, whether true or false. Thus, the four complaints among the repeat riders are probably significant. Physiological data were not obtained during this test. Later, a test was initiated at 63 RPM and 0.10 horsepower, using four healthy males, three of whom are amateur runners. The test was discontinued in one hour due to high pulse rates and blood pressures.

Optimal pedal RPM, therefore, falls between 45 and 63. During tests at 0.10 horsepower per person and 55 or 59 RPM, totaling 61 hours, only one

operator had to be relieved, and it appeared that this resulted from no one else on the shift doing his share. Since mean pulse increase is less at 55 RPM, this is the most physiologically desirable speed.

2. Horsepower: Varying the required output per person revealed that only experienced, healthy young adults can maintain 0.15 horsepower each with 7-1/2 minutes rest per half hour at a pedal speed below 56 RPM. This work rate was obtained for 19 hours, during which four operators were removed: One, a female, had been removed in a previous test at 0.09 horsepower and another one was an inexperienced, 35-year old, out-of-condition, male.

Taking 59 RPM as a near-optimum speed, increasing work loads were tested, ranging from 0.12 to 0.15. These high-work tests totaled over 50 hours. No operators had to be relieved, but 0.15 horsepower seems to be near maximum sustainable work load. Pulse increase data are sparse at this load, but it should be noted from Table VIII that 55 RPM is satisfactory, if not optimal, since pulse increase is no greater than that at 0.10 horsepower and 59 RPM.

3. Temperature: Two 24-hour tests were conducted at 59 pedal RPM with elevated effective temperature. Due to inadequacies of the temperature control system available, effective temperature varied rather widely within each test from 77 to 83 degrees Fahrenheit. In the first test, each operator was required to supply 0.09 horsepower. Physiological measures were not taken but no operators were relieved at this load.

In the other test, 0.10 horsepower per person was required. One operator was relieved due to dangerous pulse rate, and at least five others made excursions into the dangerous range (over 140). Most operators could work at this load without undue exhaustion or damage, but this combination of temperature and work load approaches a point where sustained operation is dangerous to some operators.

All other tests were conducted in the comfort range, from about 68 to 72 degrees Fahrenheit effective temperature. No difficulties due to the temperature were encountered in any of these tests.

### Symptoms of Operator Stress

In all, eleven operators were relieved from completion of their shift, three at their own request and eight on the observer's initiative. All of these eight exhibited symptoms of distress, including high pulse rate, high blood pressure, nausea, paleness, heavy perspiration, very flushed face, leg cramps, or sore legs. All, however, recovered within an hour without medical attention. Only one operator was relieved for excessive blood pressure who did not have a corresponding increase in pulse rate, and that operator has a history of high blood pressure. (See Table IX.)

TABLE IX  
OPERATORS RELIEVED BY SYMPTOMS AND SEX

Sex	<u>Relieved at Observer's Discretion</u>			<u>Relieved Voluntarily</u>	Total
	Blood Pressure	Pulse Rate	General Appearance	Exhaustion or Nausea	
Male	3	2	1	0	6
Female	$\frac{0}{3}$	$\frac{2}{4}$	$\frac{0}{1}$	$\frac{3}{3}$	$\frac{5}{11}$

It seems sufficient then, in a young adult population, to screen for general poor health or circulatory disorders and to relieve anyone whose pulse rate increase exceeds 40 per minute, or who exhibits other symptoms of undue exertion.

### Other Operating Dangers

It should be noted that none of the males were relieved voluntarily, although they exhibited dangerous symptoms. In fact, less than one third of all subjects relieved requested removal. This indicates a need during any operation of the equipment for careful monitoring of the operators.

Operators dismounting upon completion of a 22-1/2 minute stint commonly experienced "looseness" of the knees or "wobbly legs" severe enough to cause them to stagger. This could endanger small children near the ventilating apparatus, or the operator if sharp-edged objects (such as opened ration cans) are stored nearby.

As the study progressed and the adjustment of seats became more difficult, the adjusting operation became dangerous to hands, resulting in three known cases of pinched thumbs, two of them severe enough to result in the accumulation of blood beneath the nail. This apparently occurred in attempting to lower a seat, when it would suddenly give way beneath heavy pressure and fall all the way, pinching the thumb between the release bar and the underside of the seat.

#### Unusual Operating Situations

Normal procedure called for no subject pedaling for more than one shift in any 24-hour period. On four occasions, however, young athletic subjects were permitted to work two consecutive shifts under varying work-rest ratios and work loads. All subjects were males ranging in age from 18 to 26, and at no time showed extreme fatigue. Table X on page 37 is a summary of these double shifts.

The other unusual operating procedure occurred on those shifts where missing subjects limited team size or where apparatus malfunction reduced the number of operators permitted to pedal. Under these circumstances two-man shifts would operate, i.e., only two riders on the apparatus at any one time. The work-rest schedule used on these shifts was at the discretion of the shift observer. One segment on, one segment rest, or two segments on, two segments rest were normally used when a full team was available, and a two segment on, one segment rest schedule where only three subjects were present. (Refer to page 20 for definition of "segment".)

Six out of thirteen two-man shifts worked the one segment on, one segment rest schedule. Fatigue was recorded in two of them and inability to maintain speed ("lagging"), also in one of the two. The two segments on, two segments rest was performed in two shifts, no lagging or fatigue was recorded. Four

TABLE X

## SUMMARY OF DOUBLE-SHIFT OPERATION

Date	Time	First Shift (1st Three Hours) Description	Second Shift (2nd Three Hours) Description	Effective Temperature, Fahrenheit
4 April	0900-1500	Normal Test 7*	Normal Test 7*	78-81
7 April	0900-1500	Normal Test 9*	2 operators, 2 segments on - 1 segment rest schedule. Test 10*	73-74
9 April	0900-1500	Normal Test 13*	2 operators, no rest, Test 14*	70-71
12 April	0000-0600	Normal Test 13*	2 operators, 1 segment on - 1 segment rest. Test 17*	73-74

\*See Appendix B, Page 49.

shifts operated with three-man teams with the two segments on, one segment rest schedule. Fatigue and lagging were recorded for one group..

It can be noted that all the groups that recorded fatigue and/or lagging contained a predominance of female subjects. The significance of this finding will be discussed later under Team Make-Up.

The most difficult two-man shift was run on 9 April, 1200 to 1500. It involved the operation of the machine by two young male subjects, one of whom worked the shift immediately previous, for the entire three-hour shift without substantial rest (actually, each was relieved for approximately five minutes during the shift) The riders maintained 50 RPM, 5 RPM below the set speed but exhibited no fatigue.

### Hand Operation

During one shift, composed of healthy young men, hand cranking was tried out for a short period at one, two, and three positions, while any vacant positions were operated in the normal manner. This short period (about 15 minutes) was sufficient to demonstrate that, although an operator can attain 0.10 horsepower output by cranking a pedal or pair of pedals with his hands, he could not sustain this work load for three hours. It also was clear that the most efficient hand-cranking technique--powering a pair of pedals, one with each hand--was only practical at the rear position, sitting on the floor behind the apparatus. Given these limitations, this procedure seems to have merit only as a last resort in an emergency, such as complete fatigue of the legs of all possible operators, or as a means of employing a handicapped individual.

### Team Make-Up

The data on rider performance lends itself most readily to the discussion of the most efficient team make-up in terms of individual segments rather than whole shifts. It is in this way that we shall approach the subject.

As shown in Table XI, there are four possible combinations of male and female operators on any given segment. The entire study was broken down into segments operated by each combination and then each was compared with the number of times that such combination was unable to maintain required speed and a percentage was computed. Only normal schedule, four-man team shifts were counted.

The data show, as might be expected, that three female operators were most likely to lag. In other words, females are more apt to limit their output at some level which falls below their fair share. Therefore, if two "limited output" people are teamed with an individual committed to maintaining a pre-established total output level, that individual will be overworked, sometimes to a dangerous extent. Most important, perhaps, is the high per cent of lag in segments operated by one male and two females. These findings are in agreement with the data on fatigue and lagging in two-man shifts reported earlier and may also bear relation to the high incidence of male fatigue complaints also previously noted. They point to an important conclusion:

TABLE XI  
EFFICIENCY OF OPERATOR GROUP COMPOSITION IN TERMS OF PER CENT  
OF SEGMENTS REPORTED OPERATING BELOW REQUIRED SPEED

Operating Team Composition	Segments Operated	Segments Lag Recorded	Per Cent of Segments Lagged
3 Male	924	4	0.4
2 Male, 1 Female	472	4	0.8
1 Male, 2 Female	580	17	3.0
3 Female	264	14	5.0

Females, operating with a single male, tend to exert less effort, allowing the male to carry the greater portion of the load. Either the female operators should never outnumber the males, or steps should be taken to ensure that each rider does his fair share of the work. Given this fair share condition, it is quite possible that an all-female team would be able to adequately operate the PVK over an extended period of time. However, no data were obtained in this study regarding all-female operation beyond a three-hour shift.

#### In-Shelter Operator Combination

In the event of any disaster requiring shelter use, the shelter stay should normally provide many persons physically capable of operating the ventilating apparatus should the need arise. Therefore, the design of specific operator work-rest schedules becomes less important than the consideration of who should operate at a given time. Based on the discussion above, the following conclusions have been reached:

1. All male operator teams are most preferred.
2. All female operator teams are acceptable.
3. Mixed operator teams with a majority of female riders should be avoided unless each operator is made aware of the effort required of him.



It is easy to imagine a condition existing, however, in which only a very few operators would be available to power the apparatus. In such a situation, schedule considerations would become of prime importance. Only a few of the many possible work-rest combinations were examined in the exercise, but, even on the basis of such a limited sample certain conclusions can be reached:

1. No subject exhibited ill effects as a direct result of the schedule normally used in the evaluation (22-1/2 minutes work, 7-1/2 minutes rest, over a period of three hours).
2. Of the schedules attempted in the evaluation, no one schedule was either critically good or bad although, with shifts operated by only two riders, the one segment on, one segment rest was considered the most difficult.
3. On the basis of limited information, regarding two-man shifts, young male riders seem to find the two segment on, two segment rest the easiest to perform.
4. If necessary, two male riders in excellent physical condition can operate the apparatus almost without rest for up to six hours at 0.15 horsepower.

## RECOMMENDATIONS FOR FURTHER RESEARCH REGARDING OPERATING FACTORS

Conditions resulting from elevated effective temperatures were not adequately explored in this study, since the PVK operators were not confined in a high temperature environment when they were not pedaling. Conclusions regarding operation in high temperature environments should be based on studies in which the shelter population is confined for an extended period. Horsepower output and work-rest cycles should both be varied, in search of an optimal condition for each at temperatures up to 85 degrees effective temperature.

In the course of this study, on several occasions, husky men individually maintained 0.30 horsepower for a few minutes at a time. Since the economy of stocking a single-module unit as opposed to a three-module unit is apparent, it may be worth exploring the feasibility of a PVK design based on a power input to the system greater than 0.1 horsepower. If enough qualified operators are available, the long rest period possible under this system should restore each operator to full potential before his turn recurs.



## **APPENDIX A**

### **FORMS USED IN THE RECRUITMENT AND PROCESSING OF SUBJECTS**

SHELTER MANAGEMENT LABORATORY  
of the  
AMERICAN INSTITUTES FOR RESEARCH  
410 Amberson Avenue, Pittsburgh, Pennsylvania 15232  
under contract to the Office of Civil Defense

## SUBJECTS REQUIRED FOR CIVIL DEFENSE EVALUATION EXERCISE

The American Institutes for Research is conducting a series of experimental studies having to do with public fallout shelters. The studies include testing of supplies and facilities necessary for survival, and evaluating procedures for organizing and operating community shelters. The present study involves the testing of emergency shelter ventilating equipment and requires of the subject no more skill or strength than is needed to pedal a bicycle. The Institute is seeking men, women, and children to act as volunteers for this research program.

### WHEN WILL THE STUDIES TAKE PLACE?

The program will be carried out in a continuous 14 day run beginning at 3 p.m., March 29, 1965 and concluding at 3 p.m. on April 12. Each volunteer can participate as often as he desires within the limits imposed by the experimental design. Normally however, no subject will participate more than 3 hours in any one day.

### WHAT ARE SUBJECTS EXPECTED TO DO IN THE SHELTER?

Participants in the study will operate a bicycle pedal powered fallout shelter ventilation apparatus for periods of time ranging from 1 to 3 hours. Participation will be by groups of 4 and rest periods will be provided.

### REMUNERATION

Each participant will receive an honorarium of \$2.00 per hour of operating the equipment. However, participants will be expected to arrive 10 minutes prior to their scheduled starting time.

### HOW DO I APPLY?

Fill out and mail the attached form for yourself or your group, or call The American Institutes for Research, (412) 681-3000, and ask for the Shelter Research Laboratory.

SHELTER RESEARCH LABORATORY, AMERICAN INSTITUTE FOR RESEARCH  
410 Amberson Avenue, Pittsburgh 32, Pennsylvania 681 - 3000

APPLICATION FORM  
(Please Print or Type)

1. Full Name: \_\_\_\_\_ 2. U.S. Citizen: Yes \_\_\_ No \_\_\_  
3. Home Address: \_\_\_\_\_ 4. Home Phone: \_\_\_\_\_  
5. Occupation: \_\_\_\_\_ 6. Business Phone: \_\_\_\_\_  
7. Business or School Address: \_\_\_\_\_  
8. Sex: \_\_\_\_\_ 9. Age: \_\_\_\_\_  
10. Religious Preference: \_\_\_\_\_ 11. Marital Status: \_\_\_\_\_  
Ages of Children: 12. Girl(s): \_\_\_\_\_ 13. Boy(s): \_\_\_\_\_  
14. Nature of Previous Employment: \_\_\_\_\_  
15. Military Experience Rank: \_\_\_\_\_  
16. Civil Defense Experience: \_\_\_\_\_  
17. Education: Grade Completed: \_\_\_\_\_  
College Experience: \_\_\_\_\_  
18. Height: \_\_\_\_\_  
19. Weight: \_\_\_\_\_  
20. Do you have heart trouble? \_\_\_\_\_ Diabetes? \_\_\_\_\_  
21. Do you have or have you ever had any respiratory disease (TB, asthma, etc.)? \_\_\_\_\_  
22. Have you been hospitalized or had any serious illness in the last 6 months? \_\_\_\_\_  
23. Are you presently under the care of a doctor, psychiatrist, or counselor? if  
so, for what? \_\_\_\_\_  
24. Give name, address, and phone number of your personal physician. \_\_\_\_\_  
\_\_\_\_\_  
25. Have you received professional help for an emotional or nervous disorder within  
the past 3 years? \_\_\_\_\_  
26. Why are you interested in participating in this study? \_\_\_\_\_  
27. When can you participate in the study? \_\_\_\_\_  
28. Would any friends, associates, or members of your family be interested in par-  
ticipating in these studies? (Use other side if necessary.)

<u>NAME</u>	<u>AGE</u>	<u>ADDRESS</u>	<u>PHONE</u>	<u>RELATIONSHIP</u>

MEDICAL RECOMMENDATION

Name of Participant \_\_\_\_\_

Address \_\_\_\_\_

To the Physician:

The above named person has applied to the American Institutes for Research to become a subject in the experiment discribed below. On the basis of your knowledge of this person's physical condition and health history, please recom-ment this person by checking one of the alternatives listed at the bottom of this page:

A subject in this experiment would be expected to pedal a stationary bicycle apparatus under a load similiar to that required to pedal a bicycle on a smooth, level highway. Subjects will pedal approximately 20 minutes and rest 10 for periods of from 1 to 3 hours depending on experimental design and your recom-mendation. Subjects will probably not work more than a total of 3 hours in any one day but may work several days in succession.

If further information is desired call the American Institutes for Research, Shelter Research Lab, 681-3000

I recommend this person   \_\_\_  for FULL participation in the experiment as dis-  
                                  cribed above.  
                                  \_\_\_  for QUALIFIED participation (explain on reverse side).  
                                  \_\_\_  be EXCLUDED from participation.

Signiture of Physician \_\_\_\_\_ Date \_\_\_\_\_

AGREEMENT AND RELEASE

1. I, \_\_\_\_\_,  
\_\_\_\_\_ employed  
by \_\_\_\_\_

volunteer to participate in a human factors evaluation of a bicycle peddle powered fallout shelter ventilation apparatus in connection with research studies to be conducted by the American Institutes for Research in the Behavioral Sciences.

2. I understand that subjects will participate in this human factors evaluation at 400 Amberson Avenue, Pittsburgh, Pennsylvania. I realize that participation may impose physical and/or mental stresses upon me and/or the other subjects. I believe that I am physically and mentally fit to withstand any such stresses. I assume all risks of illness and injury which may occur because of my participation in said experiments. I hereby release the American Institutes for Research, its agents, employees, or representatives from all liability for any injury sustained or illness developed by me during my participation in said experiments not occasioned by any negligence on the part of the American Institutes for Research.

3. I understand that I will be observed during my participation and that my conduct and/or voice may be recorded by photographic and/or recording devices. I also realize that public reports and articles may be made of the experiments and all of the observations and consent to publication of such, including the use of photographs.

4. I hereby authorize the American Institutes for Research to remove me from the evaluation exercise at any time and for any reason. I agree to leave said exercise willingly when asked to do so.

5. I understand that I will be permitted to leave the evaluation exercise at any time that I find that I am unable to withstand the conditions and request to be relieved.

6. As compensation for my voluntary services as a participant in the aforesaid studies, the American Institutes for Research will pay me the sum of \$ 2.00 per hour of operating the apparatus. It is clearly understood and

agreed, however, that in no event am I to be considered an employee of the American Institutes for Research during such participation.

7. I hereby agree, under penalty of forfeiture of all compensation due me, not to give information regarding these studies to any public news media nor to publicize any articles or other accounts thereof without prior written approval by the American Institutes for Research.

Intending to be legally bound, I have signed and sealed the herein Agreement and Release, this \_\_\_\_\_ day of \_\_\_\_\_, 1965.

\_\_\_\_\_  
(SEAL)

WITNESS:

\_\_\_\_\_

I make the above agreements for my children, listed below.

_____	_____
_____	_____
_____	_____
_____	_____

\_\_\_\_\_  
(SEAL)

WITNESS:

\_\_\_\_\_



RECEIPT FOR SUBJECT HONORARIUM

I/We, the undersigned, hereby acknowledge receipt of \_\_\_\_\_, full payment  
of subject honorarium for participation in the Emergency Ventilation  
System Evaluation conducted by the American Institutes for Research this  
day, \_\_\_\_\_.

Time began \_\_\_\_\_ AM  
PM

Time finished \_\_\_\_\_ AM  
PM

Signed \_\_\_\_\_

(Seal) \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



## **APPENDIX B**

### **SUMMARY OF PEDAL SPEED, INPUT LOAD, AND EFFECTIVE TEMPERATURE TESTS**

TABLE XII

SUMMARY OF TESTS

Test No.	Period of Test 1955	Duration of Test (Hours)	No. of Operators Working/Resting	Work/Rest Cycle (Minutes)	Pedal Speed (RPM)	Horse Power		Air Flow (CFM)	Static Pressure (inches H <sub>2</sub> O)	Average Air Temperature (F)		
						Fan BHP	Input HP			D&T	WBT	ET
1	29 Mar 1700-1900	2	3/1	22.5/7.5	51.5	0.12	0.13	2510	0.12	No Data (Comfort Range)		
2	29 Mar 1900 to 30 Mar 1700	22	3/1	22.5/7.5	51.5	0.25	0.30	970	0.52	No Data (Comfort Range)		
3	30 Mar 1700 to 31 Mar 1700	24	3/1	22.5/7.5	60.0	0.23	0.30	1750	0.47	75.3	58.3	63.5
4	31 Mar 1700 to 1 Apr 1700	24	3/1	22.5/7.5	67.0	0.27	0.30	3200	0.15	77.9	60.7	70.3
5	1 Apr 1700 to 2 Apr 1600	23	3/1	22.5/7.5	59.0	0.34	0.37	1460	0.55	73.3	53.3	72.0
6	2 Apr 1600 to 3 Apr 1700	25	3/1	22.5/7.5	59.0	0.33	0.41	1020	0.70	79.5	62.6	72.2
7	3 Apr 1700 to 4 Apr 1700	24	3/1	22.5/7.5	59.0	0.25	0.27	1930	0.41	90.0	59.6	79.0
8	4 Apr 1700 to 5 Apr 1800	25	3/1	22.5/7.5	59.0	0.28	0.30	1760	0.46	89.7	70.5	79.2
9	5 Apr 1800 to 7 Apr 1200	42	3/1	22.5/7.5	59.0	0.23	0.30	1760	0.46	75.5	64.6	72.4
10	7 Apr 1200-1500	3	2/1	15.5/7.5	59.0	0.23	0.30	1760	0.46	79.2	67.3	73.6
11	7 Apr 1500 to 9 Apr 0000	33	3/1	22.5/7.5	45.0	0.23	0.30	0	0.70	80.7	66.8	74.1
12	9 Apr 0000-0100	1	3/1	22.5/7.5	63.0	0.23	0.30	2400	0.37	73.0	65.0	72.0
13	9 Apr 0100-1200 9 Apr 1500 to 10 Apr 0000 10 Apr 0900-1100 10 Apr 2100 to 12 Apr 0300	52	3/1	22.5/7.5	55.0	0.23	0.30	1450	0.46	77.5	64.7	72.0
14	9 Apr 1200-1500	3	2/0	180/0	55.0	0.23	0.30	1450	0.46	76.6	63.0	71.0
15	10 Apr 0000-0300	3	3/2	24-work 12-rest 12-work 12-rest	59.0	0.33	0.36	1560	0.53	74.0	62.5	59.5
16	10 Apr 0300-0900 & 1100-2100	16	2/2	7.5/7.5	55.0	0.23	0.30	1450	0.46	76.1	62.4	70.6
17	12 Apr 0300-1200	9	2/2	7.5/7.5	48.0	0.23	0.30	460	0.57	77.0	67.0	72.5
18	12 Apr 1200-1800	6	2/2	7.5/7.5	45.0	0.23	0.30	0	0.70	77.0	67.0	72.5



## **APPENDIX C**

### **ELECTRICAL RECORDING OF HEART RATE**

## ELECTRICAL RECORDING OF HEART RATE

Prior to evaluating the fallout shelter ventilation apparatus, the need for physiological measurements was clearly recognized. One of the measures considered to be indicative of operator exertion was heart rate. For this reason, the selection of an electrocardiographic instrument was made. The instrument used was a single channel, portable model. This type of instrument, while permitting recording from only one patient at a time, had the advantage of being easily operated in the limited space of the simulated fallout shelter. The experimenter could easily place the instrument at a convenient location to the operator, set up, and begin recording in about five to seven minutes. Actual recording was at various intervals during the operator's pedaling shift with a minimum of eight minutes elapsed time available for recording. This minimum recording period could be extended to the entire pedaling shift, with time available for pre- and post-pedaling measures, by placing the electrodes on the operator before he mounted the ventilation apparatus. With the electrodes pre-placed, the operator could mount and dismount with only minimal restrictions imposed by the patient cable.

Two similar electrode placements were employed to obtain heart rate measures from male and female operators. Both are described below and both used a total of three electrodes, positioned on the arms and chest, or only on the arms. The remaining two electrode leads were unused. It should be noted that the records obtained with the apparatus, while yielding excellent heart rate measures, were not intended to be diagnostic cardiograms. For this reason, no attempt was made to obtain wave complexes of clinical quality.

Before beginning the discussion of recording methodology, a brief explanation of terms is necessary. The term "patient cable" refers to the five-conductor cable connecting the individual electrodes to the recording instrument. Individual conductors in this cable are referred to as

"electrode leads" in the discussion. The term "lead", used singularly, applies to the combination of two or more conductors ("electrode leads") on the operator that are necessary for recording any electrocardiogram. These combinations are designated according to number or letter(s) directly corresponding to the markings on the lead selector switch of the cardiographic instrument. In other words, the term "AVL lead" refers to the combination of "electrode leads" that are actually recording heart rate when the selector switch is in the AVL position.

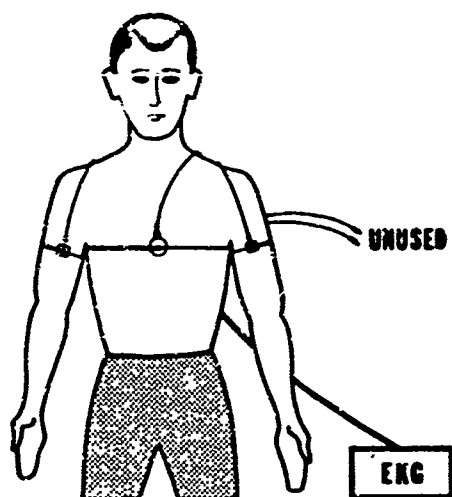
#### Method I

The first method to be discussed is one which is employed to best advantage when working with a male population. Limiting this method to males is based on a consideration of ethics rather than technology. A chest electrode is employed at the center of the chest, on a line with the underside of the arms, with the arms extended at 90 degrees to the body. The remaining two electrodes are positioned on the inside of each of the forearms. The electrode leads are: left arm electrode lead to left arm electrode, chest electrode lead to chest electrode, right leg electrode lead to right arm electrode. The electrode leads for the right arm and left leg were unused and insulated from each other and the patient. (See Figure 8, number 1, on page 54.)

All electrodes were applied to the skin using electrode jelly to facilitate proper contact and held in place by the conventional rubber electrode straps. A rubber strap was also used to secure the chest electrode. The chest electrode strap, at the same time, held the patient cable to the operator. This was accomplished by passing the patient cable under the strap at a point just below and on center with the back of the shoulders. (See Figure 8, number 3, on page 54.) The individual electrode leads were then passed over the shoulders and connected to the appropriate electrodes. Recordings were then taken using the lead selector switch at the "C" position, i.e., chest. Recording under these conditions yielded the best recording in terms of the nearly perfect wave complex form. (See Figure 9 on page 55.) These complexes represent those most closely approximating those employed

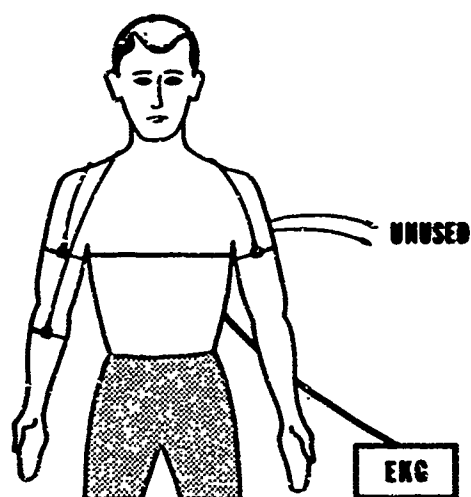
1

METHOD I



2

METHOD II



3

POSITION OF  
PATIENT CABLE  
ON THE BACK

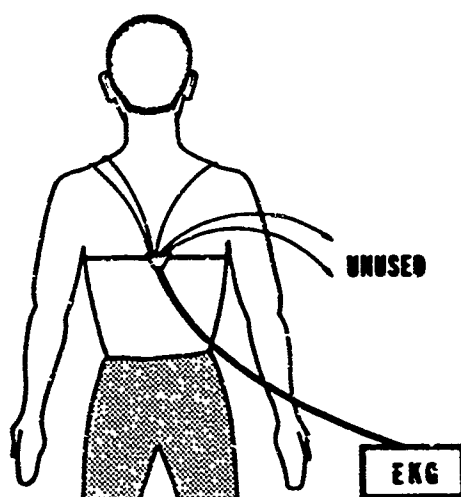
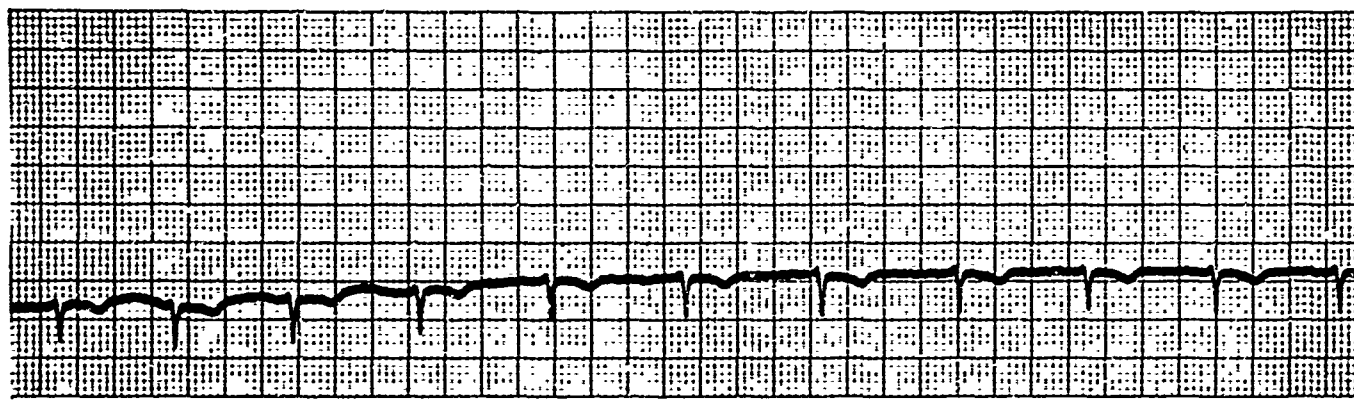


Figure 8 SCHEMATIC OF ELECTRODE PLACEMENT

The tracings were taken with the instrument selector switch in the  
"C" position at a paper speed of 25MM/Sec.

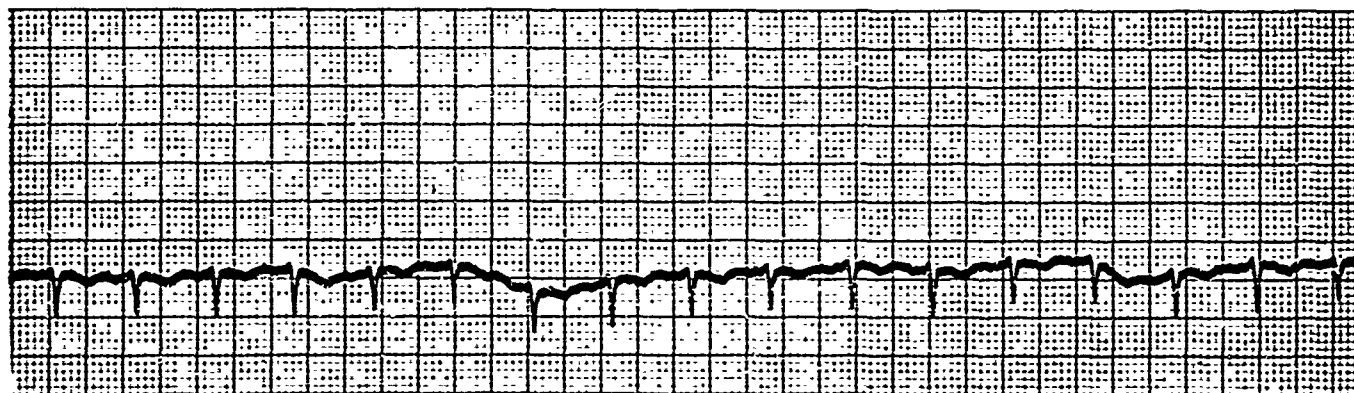
**Resting**



**Heart Rate: 85/Min.**

**Chest Lead**

**After 3 Minutes Pedaling**



SANBORN VISO CARDIETTE *Permapaper*

**Heart Rate: 140/Min.**

**Chest Lead**

Figure 9 CARDIOTACHOGRAPHY METHOD I.



in clinical diagnosis. While in some cases this may facilitate easier heart rate measure, the limit placed on the use of the technique to males only makes the second method to be discussed more applicable under the experimental conditions.

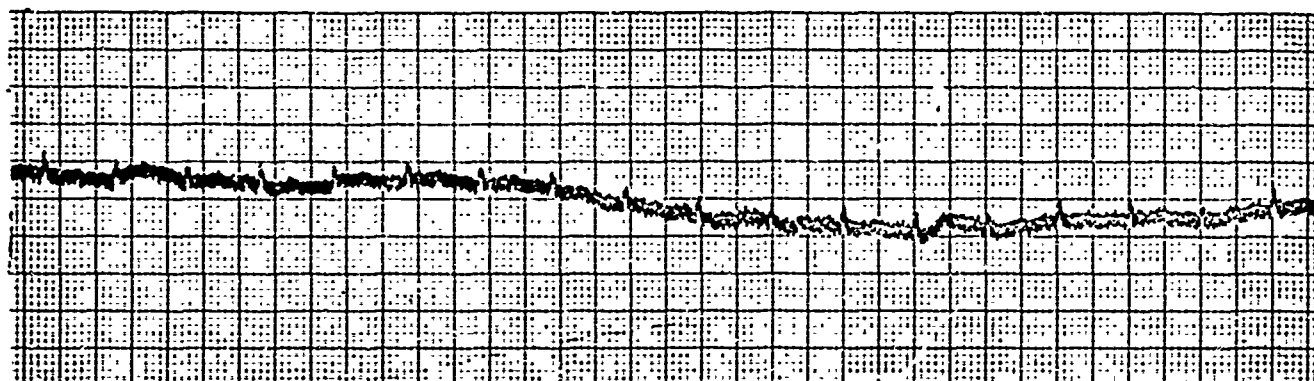
#### Method II

This method was employed on a female operator, hence the chest electrode was not used. The chest electrode was replaced by the right arm electrode. Under this condition the electrodes were placed on the arms only. Placement was as follows: upper right arm, right arm electrode lead; lower right arm, right leg electrode lead; upper left arm, left arm electrode lead. (See Figure 8, number 2, on page 54.) With this electrode placement and lead selection, the records were taken with the instrument lead selector switch set either at the number one, AVL, or AVR position.

Preparation of the operator and securing of leads and electrodes were the same as described in Method I. Briefly, the electrodes were secured with rubber straps, and electrode/skin contact was facilitated by electrode jelly. The rubber chest electrode strap was used again, but only to secure the patient cable to the operator. (See Figure 8, number 3.) In this manner, acceptable cardiographic tracings were obtained. (See Figure 10, page 57.)

Examination of the records obtained shows that the changes in electrode placement and the choice of electrodes used significantly alter the wave complex form. From the standpoint of diagnosis, this change is of critical importance, but for the purpose of cardiography the records are completely adequate. Considering the ease of preparation and general applicability to both male and female operators, this method is considered to be superior for cardiographic use.

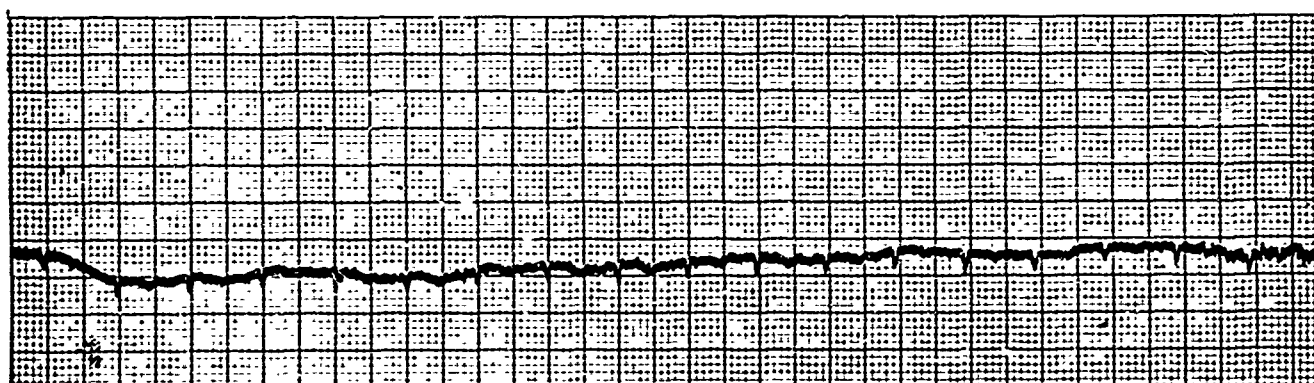
Recording taken at paper speed of 25 MM/Sec. after 3 minutes of pedaling



SANBORN VISO (

Heart Rate: 150/Min.

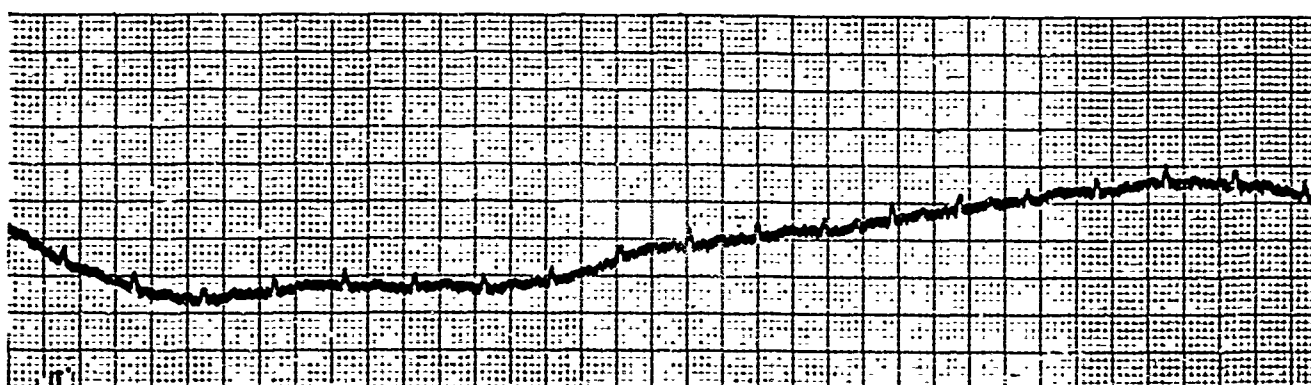
Lead #1



SANBORN VISO CARDIETTE *Permapaper*

Heart Rate: 150/Min.

AVR Lead



SANBORN VISO CARDIETTE *Permapaper*

Figure 10 CARDIOTACHOGRAPHY METHOD II <sup>AVL Lead</sup>

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13. ABSTRACT  The human factors and structural analysis test showed that the Civil Defense shelter ventilating fan can be driven easily at pedal speeds from 45 to 62 rpm, and at an input power of 0.15 horsepower per operator. All structural failures have been corrected, and the unit is to be retested prior to releasing Specification MIL-V-40645, "Package Ventilation Kit, 20-Inch Fan, Modular Drive (Civil Defense)".		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
CIVIL DEFENSE SYSTEMS FALLOUT SHELTERS MACHINES PORTABLE SPECIFICATIONS COOLING & VENTILATING EQUIPMENT VENTILATION DESIGN TESTS						

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SUMMARY  
OF  
RESEARCH REPORT

EXPERIMENTAL PROTOTYPE PACKAGE VENTILATION  
KIT, FIRST STRUCTURAL AND  
HUMAN FACTORS TEST

GARD Report 1278-4.1

May 1965

by

General American Transportation Corporation  
General American Research Division  
Environmental Research Group  
Niles, Illinois

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VIEW OF TEST SET-UP

GENERAL AMERICAN RESEARCH DIVISION

### ABSTRACT

A 337-hour structural and human factors test of the Civil Defense fallout shelter Package Ventilation Kit (PVK) consisting of a fan assembly and three drive modules (see opposite page) was conducted by the General American Transportation Corporation (GATX) and the American Institutes for Research (AIR) at the latter's Research Shelter Management Laboratory located at Pittsburgh, Pennsylvania. This test showed that the ventilator can be readily operated for periods of at least three hours with 7-1/2 minutes rest each half-hour. The PVK can be operated at pedal speeds from 45 to 63 RPM, and the preferred speed was 55 RPM. The optimum power input was found to be 0.10 horsepower per operator, the maximum tested was 0.15. Most tests were performed at comfortable conditions, 68 to 72 F effective temperature (ET). The maximum ET imposed was 83 F. Further tests are required to establish work/rest cycles when operating the PVK at elevated ET's.

This experimental prototype unit operated adequately for 331 hours, and then marginally for another six hours due to sprocket wear. As a result, the PVK specifications were revised to require hardened sprockets. One chain spring clip failed during the test; therefore, endless riveted chain has been specified. No chain wear was indicated. The saddle post rapid adjustment clamp caused jamming of the post. Since the seats are not adjusted frequently, this feature has been deleted and the standard saddle clamp is now specified. A clutch has been included in the crank assembly, but was not used during the test. Since no need for this device was expressed by either operators or observers, and since the clutch is expensive, the clutch has been deleted. Other observations have affected the design of the saddle, handle bar, and connecting joint. These design changes have been incorporated into the drawings and specifications. Prior to fabricating preproduction prototype Package Ventilation Kits, GARD recommends that another structural test be performed on the PVK. See GARD Report 1278-4.2, "Preproduction Prototype Package Ventilation Kit, Second Structural and Human Factors Test", performed by GARD and AIR under OCD Work Unit 1423A, SRI Subcontract No. B-70925(4949A-28)-US.